Re-visiting the Porter Hypothesis

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Abstract

We provide a new formulation of the Porter hypothesis that we feel is in the spirit of the hypothesis. Under this formulation we find that the Porter hypothesis need not hold universally, and identify conditions under which it may or may not hold. We first consider the case where the abatement costs associated with a technology is exogenously given. In that case stricter government regulation increases the incentive for adopting the new technology if the old and the new technologies are relatively environmentally friendly to begin with. We then consider the case where the abatement costs associated with a technology is endogenously given. We show that the Porter hypothesis is likely to hold if the new technology is significantly more efficient in production compared to the old technology, or if both the technologies are relatively efficient in production. Whereas if both the technologies are relatively inefficient, then the Porter hypothesis is unlikely to go through. Thus, under the appropriate conditions, the Porter hypothesis may hold even in a static framework.

Key words: Porter hypothesis, environmental policy, R&D.
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Re-visiting the Porter Hypothesis

Introduction

The traditional approach to environmental policy consists of comparing the beneficial effects of environmental regulation with the cost that must be borne to secure these benefits. It is out of this benefit-cost approach that the standard trade-off discussed in virtually every environmental economics text book emerges.

Porter and van der Linde (1995) deny the validity of this approach, claiming that it ignores the fact that environmental regulation leads to greater innovations. Thus in their view there is no trade off, as it has been observed in many cases that the enforcement of environmental regulations not only reduce environmental damage, but also lead to cost efficient product quality. This is the well known *Porter Hypothesis*.[1]

The major empirical evidence that Porter and van der Linde (1995) suggest in support of their claim is a series of case studies. But with literally hundreds of thousands firms subject to environmental regulations in United States alone, it would not be hard to find instances where regulation has seemingly worked to a polluting firm's disadvantage. It has thus been argued that collecting cases where this has happened in no way establishes a general presumption in favor of this outcome.

The Porter hypothesis has also been criticized by Palmer, Oates and Portney (1995) who argue that there is always a trade-off between environmental regulation and competitiveness. They use a simple static model to make the point that if technology was not worth investing in before, then its benefits will not be enough to fully offset the costs of compliance after stricter regulations are enforced.

In this paper we analyze this question in a theoretical framework. We consider a model with a single monopoly firm producing a dirty product. This firm can either choose an existing technology, or a new technology which is more efficient in production. We first consider the case where the abatement costs associated with a technology is exogenously given. In that case stricter government regulation increases the incentive for adopting the new technology if the old and the new technologies are relatively environmentally friendly to begin with.

Given that the case for the Porter hypothesis is based on R&D

induced by environmental regulations, we then consider a framework where the production technology is exogenously given, but the emission technology is endogenously determined through R&D.

We examine a dirty industry where production leads to pollution, the level of pollution being monotonically related to the level of output. The government uses several policy measures, e.g. imposing emission taxes etc., so as to control the pollution. All these policy measures create an abatement cost for the firms. Clearly the stricter the governmental policy, the higher is the abatement cost.

One of the main contributions of this paper is to provide a new formulation of the Porter hypothesis. For example, this is different from the formulation adopted by Palmer, Oates and Portney (1995). We argue, however, that our formulation is consistent with the spirit of the Porter hypothesis.

We then briefly describe our main results. We show that the incentive to adopt the new technology is increasing with stricter government regulation if the new technology is significantly more efficient in production compared to the old technology, or if both the technologies are relatively efficient in production (in a sense made formal later in the paper). In that case there are parameter values for which the Porter Hypothesis holds. Whereas if both the technologies are relatively inefficient (in a sense made formal later), then the Porter hypothesis is unlikely to go through.

We then briefly relate our paper to the literature. The paper closest to our own is Palmer, Oates and Portney (1995). In a similar simple static framework, they argue that the Porter hypothesis cannot hold. In contrast, we find that under the appropriate framework the Porter hypothesis may go through. This is because our formulation of the Porter hypothesis is different from that in Palmer, Oates and Portney (1995). Other papers that seek to justify the Porter hypothesis adopt a dynamic framework. Thus one of the main contributions of this paper is to argue that the Porter hypothesis goes through under a simple static framework and is thus of wider applicability than is suggested by the literature.

II. Exogenous Emission technology

The market comprises one monopolist whose demand function is given by

$$q = a - p. \tag{1}$$

The cost function has three components, production cost, abatement cost, and cost of R&D. The production cost is given by

$$c_i q. \tag{2}$$

Note that the subscript denotes the technology, where $i = 0$ refers to the existing technology, and $i = 1$ refers to a new technology. The new technology is more cost efficient, i.e. $c_0 > c_1$. Moreover, adopting the new technology involves a fixed cost of F.

The abatement cost function is given by

$$Ae_i q, \tag{3}$$

where e_i is the index of emission. Thus the total pollution is $e_i q$.[2]

The existing technology is captured by the parameters (c_o, e_o). Thus for the existing technology the production cost function is given by $c_0 q$, and the abatement cost function is given by $Ae_0 q$. Another new cost efficient technology available to the firm is characterized by the parameters (c_1, e_1), with the production cost function $c_1 q$, and the abatement cost function $Ae_1 q$.

In this section we assume that all the technologies are exogenously given. In the next section we allow for the case where the technologies are endogenously chosen through R&D.

We solve for the optimal technology choice of the firm using the backwards induction logic.

We first consider the case where $e_1 < e_o$, $c_1 < c_o$, i.e. the new technology is more cost efficient and environment friendly compared to the existing technology.

Let the monopolist's profit function under the existing technology be

$$\pi_o = q(a - q) - c_o q - Ae_o q. \tag{4}$$

Therefore the first-order condition of profit maximization is given by[3]

$$\begin{aligned} \frac{d\pi_o}{dq} &= a - 2q - c_o - Ae_o = 0, \\ \text{or, } a - 2q &= Ae_o + c_o. \end{aligned} \tag{5}$$

Therefore, the equilibrium level of output under the old technology q_o^e is given by

$$q_o^e = \frac{a - c_o - Ae_o}{2}, \tag{6}$$

and the equilibrium profit level under the existing technology is

$$\pi_o^e = pq_o^e - c_o q_o^e - Ae_o q_o^e. \tag{7}$$

Substituting the value of q_0^e we obtain,

$$\pi_o^e = \frac{1}{4}(a - c_o - Ae_o)^2. \tag{8}$$

Similarly for the new technology the equilibrium level of output

$$q_1^e = \frac{1}{2}(a - c_1 - Ae_1), \tag{9}$$

and the equilibrium level of profit

$$\pi_1^e = \frac{1}{4}(a - c_1 - Ae_1)^2. \tag{10}$$

Let F denote the setup cost of adopting the new technology, including any licensing fee required for adopting the new technology.

Therefore the incentive for adopting the new technology

$$\begin{aligned} \in= & \quad \pi_1^e - F - \pi \\ = & \quad \frac{1}{4}[a - c_1 - Ae_1]^2 - F - \frac{1}{4}[a - c_o - Ae_o]^2. \end{aligned} \tag{11}$$

Next observe that

$$\begin{aligned} \frac{\partial \in}{\partial A} &= \frac{1}{4}2[a - c_1 - Ae_1](-e_1) - \frac{1}{4}.2[a - c_o - Ae_o](-e_o) \\ &= \frac{e_o(a - c_o - Ae_o)}{2} - \frac{e_1(a - c_1 - Ae_1)}{2}. \end{aligned} \tag{12}$$

We then consider the case where $e_0 = e_1 = e$, but $c_o \neq c_1$. Define

$$f^i(e) == \frac{e(a - c_i - Ae)}{2}, i = 0, 1. \tag{13}$$

Note that $f^i(e)$ is strictly concave in e with $f^i(0) = 0$ which attains a maximum at

$$e_i^* = \frac{a - c_i}{2A}. \tag{14}$$

Clearly,

$$\frac{\partial \in}{\partial A} = f^0(e_0) - f^1(e_1). \tag{15}$$

We focus on the case where $c_1 < c_0$. Then $e_0^* < e_1^*$ and $f^0(e) < f^1(e)$, for all e.

First consider the case where e_1 is very small (please see figure 1). We then note that $\lim_{e_1 \to 0} f^1(e_1) = 0$ and thus $\lim_{e_1 \to 0} \frac{\partial \in}{\partial A} = f^0(e_0) > 0$. Hence from the continuity of f^i it follows that if e_1 is very small compared to e_o, then an increase in government regulation would increase the incentive for the adoption of the new environment friendly technology i.e. $\frac{\partial \in}{\partial A} > 0$.

Next consider the case where $e_1 < e_0$, but close to e_0 (please see figure 2). Note that $\lim_{e_1 \to e_0} \frac{\partial \in}{\partial A} = f^0(e_0) - f^1(e_0) < 0$, since $f^0(e) < f^1(e)$, for all e. Hence from the continuity of f^i it follows that if e_1 is very close to e_o, then an increase in government regulation would decrease the incentive for the adoption of the new environment friendly technology i.e. $\frac{\partial \in}{\partial A} < 0$.

Summarizing the above discussion we can now write down our next proposition.

Proposition 1. *Suppose that $e_1 < e_1^*$, $e_o < e_o^*$, and $c_1 < c_o$, i.e. the new technology is more cost efficient, as well as more environment friendly.*

(i) If $e_1 < e_o$, and e_1 is very small compared to e_o, in the sense that $e_0(a - c_0 - Ae_0) > e_1(a - c_1 - Ae_1)$, then an increase in government regulation would increase the incentive for the adoption of the new environment friendly technology.

(ii) If $e_1 < e_o$, but significantly close to e_o, in the sense that $e_0(a - c_0 - Ae_0) < e_1(a - c_1 - Ae_1)$, then an increase in government regulation (i.e. A), would decrease the incentive for the adoption of new environment friendly technology.

Note that Proposition 1(i) can be interpreted as an explanation of the Porter Hypothesis. The intuition is as follows. With an increase in A, the abatement cost in the existing technology increases. Since e_1 is very small the abatement cost in the new technology does not increase at the same rate. Thus the new technology becomes relatively more attractive. Note that this is the straight forward application of the *replacement effect* first identified by Arrow (1962).

III. Endogenous Emission Technology

In this section we assume that the level of e_i is endogenously determined by R&D. To begin with the two technologies are equally environment friendly with a common emission parameter of $\widehat{e}$. The R&D cost function is

$$r(\widehat{e} - e_i)^2, \tag{16}$$

where r is the index of R&D cost.

For any given level of A, we consider the following 2 stage model:

Stage 1: The firm decides on which technology to adopt.
Stage 2 : The firm decides on the level of R&D and production.

We use a standard backwards induction argument to solve the model. The profit function of the monopolist is given by

$$\pi_i(q_i, e_i) = q_i(a - q_i) - c_i q_i - A e_i q_i - r(\widehat{e} - e_i)^2. \tag{17}$$

Thus the first-order conditions are:[4]

$$\begin{aligned} \frac{\partial \pi_i(q_i, e_i)}{\partial q} &= a - 2q_i - c_i - A e_i = 0, & (18) \\ \text{and, } \frac{\partial \pi_i(q_i, e_i)}{\partial e_i} &= -A q_i + 2r(\widehat{e} - e_i) = 0. & (19) \end{aligned}$$

Solving the two first order conditions simultaneously we obtain the optimal level of output and the emission index:

$$\begin{aligned} e_i^* &= \frac{A c_i + 4r\widehat{e} - aA}{4r - A^2}, & (20) \\ \text{and, } q_i^* &= \frac{2r(aA - A^2\widehat{e} - A c_i)}{A(4r - A^2)}. & (21) \end{aligned}$$

Let us define the equilibrium profit of the monopolist

$$\Pi_i(A) = \pi_i(q_i^*, e_i^*). \tag{22}$$

We are now in a position to provide a definition of the Porter Hypothesis in our framework.

Definition. *The Porter Hypothesis holds for certain parameter values* A, A^* and F, $A^* > A$, *if*

(i) $\Pi_0(A) > \Pi_1(A) - F$*, and*
(ii) $\Pi_0(A^*) < \Pi_1(A^*) - F$.

Thus we say that the Porter Hypothesis holds if, for a low level of A, the firm chooses the existing technology, whereas for a higher level of A, the firm chooses the new technology.

Why do we adopt this definition? Let $A < A^*$. We are interested in a situation where the welfare under A and the old technology is lower than that under A^* and the new technology. Under such a situation the question is whether the firms can be induced to choose the new technology through an appropriate choice of A. It is precisely this question that is addressed by our interpretation, where note that conditions (i) and (ii) are concerned with the firm's incentive for adopting the new technology.

Note that our definition of the Porter hypothesis is different from that adopted by Palmer, Oates and Portney (1995). Under the Palmer, Oates and Portney (1995) approach the Porter hypothesis is said to hold if there exists parameter values A, A^* and F, $A^* > A$, such that (i) $\Pi_0(A) > \Pi_1(A) - F$ and (ii) $\Pi_0(A) < \Pi_1(A^*) - F$. It is easy to show, mimicing the arguments given in Palmer, Oates and Portney (1995), that in this sense the Porter hypothesis can never hold.[5]

We feel that our alternative definition is not inconsistent with the spirit of Porter and van der Linde's (1995) argument, and provides a way forward from the impasse reached through the Palmer, Oates and Portney (1995) definition.

We then proceed with the analysis. From our earlier analysis we obtain

$$e_1^* < e_0^*.$$

Thus per unit pollution is lower under the new technology than under the existing technology.

Next let $I(A)$ denote the incentive for adopting the new technology. Then the monopoly firm opts for the new technology if and only if

$$I(A) = \Pi_1(A) - F - \Pi_0(A) > 0. \tag{23}$$

Next note that

$$\begin{aligned}\frac{dI(A)}{dA} &= \frac{d}{dA}[\Pi_1(A) - F - \Pi_0(A)] = \frac{d\Pi_1(A)}{dA} - \frac{d\Pi_0(A)}{dA} \\ &= \frac{\partial\Pi_1(A)}{\partial A} - \frac{\partial\Pi_0(A)}{\partial A} = e_0^* q_0^* - e_1^* q_1^*, \end{aligned} \tag{24}$$

where the above equation follows from the envelope theorem. Thus the incentive to adopt the new technology is increasing in A if and only if the equilibrium level of pollution under the existing technology is greater than that under the new technology.

Next, note that

$$\frac{dI(A)}{dA} = \frac{2r}{(4r-A^2)^2}[(Ac_o+4r\widehat{e}-aA)(a-A\widehat{e}-c_o)-(Ac_1+4r\widehat{e}-aA)(a-A\widehat{e}-c_1)]. \tag{25}$$

We then define

$$\begin{aligned} \nabla(c) &= (Ac+4r\widehat{e}-aA)(a-A\widehat{e}-c), && (26)\\ \nabla_0 &= \nabla(c_0) = (Ac_0+4r\widehat{e}-aA)(a-A\widehat{e}-c_0), && (27)\\ \text{and, } \nabla_1 &= \nabla(c_1) = (Ac_1+4r\widehat{e}-aA)(a-A\widehat{e}-c_1). && (28) \end{aligned}$$

Therefore,

$$\text{sign}\ \frac{dI}{dA} = \text{sign}\ [\nabla_0 - \nabla_1]. \tag{29}$$

Next let

$$c^* = \arg\max_c \nabla(c) = \frac{2aA - \widehat{e}\left(A^2+4r\right)}{2A}, \tag{30}$$

and note that

$$\frac{\partial^2 \nabla(c)}{\partial c^2} = -2A < 0. \tag{31}$$

Thus $\nabla(c)$ is strictly concave.

We then examine the effect of a change in A on the incentive to adopt the new technology (please see figure 3).

First, suppose that $c_1 < c_0 < c^*$. Then, from the concavity of $\nabla(c)$ and the fact that it achieves its maximum at c^*, it is clear that $\nabla_0 > \nabla_1$. Thus, $\frac{dI(A)}{dA} > 0$.

Next consider the case where $c^* < c_1 < c_0$. Mimicing the earlier argument we have that $\nabla_0 < \nabla_1$. Thus, $\frac{dI(A)}{dA} < 0$.

Finally we examine the case where $c_1 < c^* < c_0$. Suppose c^0 is not too large in the sense that there exists $c(c_0)$ such that $\nabla(c(c_0)) = \nabla(c_0)$. Then, for all $c_1 < c(c_0)$, we have that $\nabla_0 > \nabla_1$. Thus $\frac{dI(A)}{dA} > 0$.

Summarizing the above discussion we obtain our next result.

Proposition 2. *(i) Per unit pollution is lower under the new technology than under the existing one.*

(ii) If $c_1 < c_o < c^*$, then $\frac{dI(A)}{dA} > 0$. Thus the incentive to adopt the new technology is increasing with stricter government regulation. Moreover, the aggregate pollution level is greater under the existing technology.

(iii) Suppose $c_1 < c^* < c_0$ and there exists $c(c_0)$ such that $\nabla(c(c_0)) = \nabla(c_0)$. Then, for all $c_1 < c(c_0), \frac{dI}{dA} > 0$. Thus the incentive to adopt the new technology is increasing with stricter government regulation. Moreover, the aggregate pollution level is greater under the existing technology.

(iv) If $c^* < c_1 < c_o$, then $\frac{dI}{dA} < 0$. Thus the incentive to adopt the new technology is decreasing with stricter government regulation. Moreover, the aggregate pollution level is lower under the existing technology.

Proposition 2 demonstrates that the Porter hypothesis is likely to go through if both the technologies are 'efficient' (in the sense that $c_0, c_1 < c^*$), whereas it is unlikely to go through if the technologies are 'inefficient' (in the sense that $c_0, c_1 > c^*$).

Finally, it is simple to demonstrate that there exists parameter values under which the Porter Hypothesis goes through. Suppose that that the hypothesis of Propositions 2(ii), or 2(iii) hold, so that $\frac{dI(A)}{dA} > 0$. Then for all $A < A^*$, $\Pi_1(A^*) - \Pi_0(A^*) > \Pi_1(A) - \Pi_0(A)$. Thus there exists some F such that $\Pi_1(A^*) - \Pi_0(A^*) > F > \Pi_1(A) - \Pi_0(A)$. Hence

(i) $\Pi_0\,(A) > \Pi_1\,(A) - F$, and

(ii) $\Pi_0\,(A^*) < \Pi_1\,(A^*) - F$.

Thus the Porter hypothesis holds for these parameter values.

IV. Conclusion

Porter and van der Linde (1995) argue that environmental regulations not only reduce environmental damage, but also leads to efficiencies in production, or improvements in product quality. This is the *Porter hypothesis*. In this paper we provide a new formulation of the Porter hypothesis that we feel captures the spirit of the hypothesis. Under this formulation we find that the Porter hypothesis need not hold universally, and identify conditions under which it may or may not hold. We first consider the case where the abatement costs associated with a technology is exogenously given. In that case stricter government regulation increases the incentive for adopting the new technology if the old and the new technologies are relatively environmentally friendly to begin with. We then consider the case where the abatement costs associated with a technology is endogenously given. We show that the Porter hypothesis is likely to hold if the new technology is significantly more efficient in production compared to the old technology, or if both the technologies are relatively efficient in production. Whereas if both the technologies are relatively inefficient, then the Porter hypothesis is unlikely to go through. Thus, under the appropriate conditions, the Porter hypothesis may hold even in a static framework and is thus of wider applicability than is suggested by the literature.

Endnotes

1. Cropper and Oates (1992) and Bockstael and McConnell (1983) also suggest that there is a complementarity between environmental quality and industrial competitiveness. In some recent follow up work Murthy and Kumar (2001) have examined panel data of 92 water polluting firms in India. They have shown that the technical efficiency of firms increases with the intensity of environmental regulation and water conservation effort.

2. We are indebted to an anonymous referee for comments that helped us clarify our ideas regarding the interpretation of the linear abatement cost function. The linear abatement cost can be interpreted as a limiting case of a convex abatement cost function. In fact, one typical convex cost is where it is linear up to a level, and then increases abruptly beyond that. We can think of our model as applying to the linear section, before the increasing part kicks in. Furthermore, the abatement cost can be interpreted as a tax on emissions. Since, for simplicity, such taxes are often linear, so will be the abatement cost function. Finally, note that the abatement cost parameter used here is a linear version of the abatement cost used by Barrett (1994).

3. Note that $\frac{d^2\pi_0}{dq^2} = -2 < 0$. Thus the second order condition is satisfied.

4. It is easy to check that the second order condition implies that $4r - A^2 > 0$. In what follows we assume that this is satisfied.

5. The argument is simple. Suppose that $\Pi_0(A) > \Pi_1(A) - F$. Since $A^* > A$, from a simple revealed preference argument we have that $\Pi_1(A) - F \geq \Pi_1(A^*) - F$. Hence putting the two inequalities together we have that $\Pi_0(A) > \Pi_1(A^*) - F$, which violates condition (ii).

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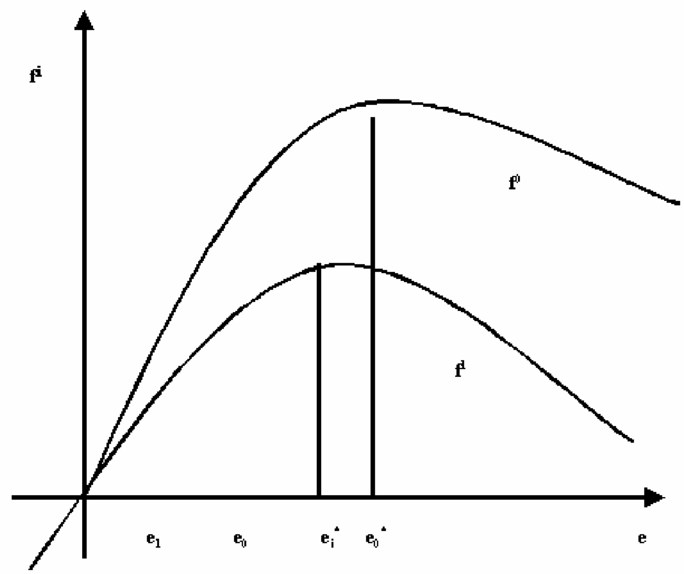

Figure -1

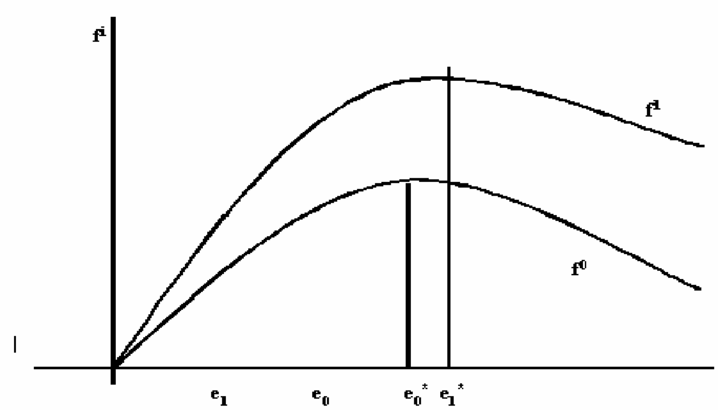

Figure 2

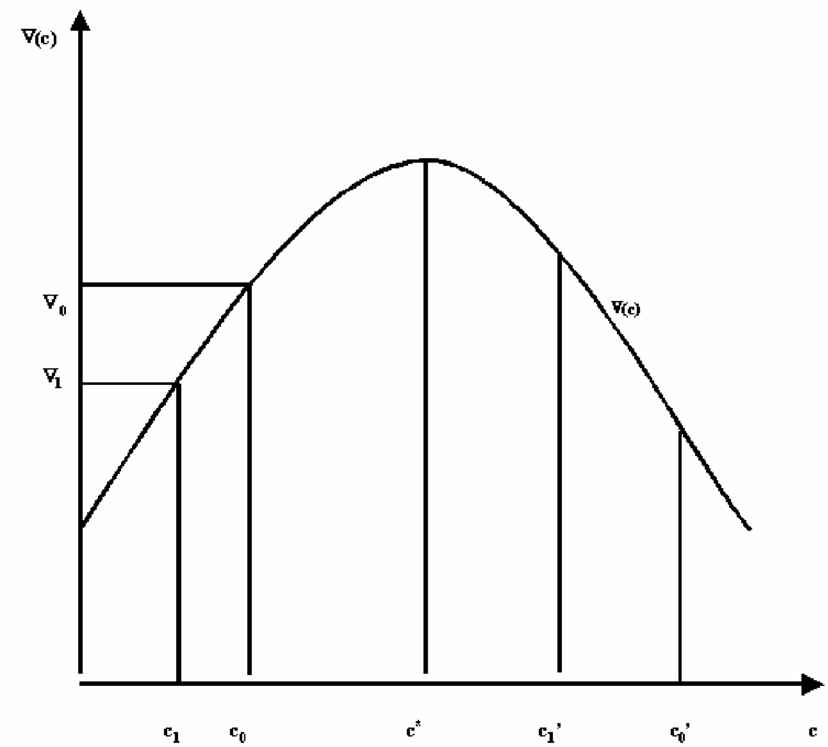

Figure-3